Formulas and Tables

FOR HEATING

BEING

GERMAN FORMULAS AND TABLES FOR HEATING AND VENTILATING WORK FOR THOSE WHO PLAN OR ERECT HEATING APPARATUS

BY

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PREFACE.

This little book contains formulas and tables which have been translated from the works of German writers, and which were published in serial form in *The Metal Worker*, in order to give those who have to do with heating and ventilation a knowledge of the latest and best work in regard to the transmission of heat through walls and windows, and the methods used to-day by the best German engineers to determine the heat losses of buildings. A proper use of the various formulas and tables which it contains will enable any-one to determine the heat lost through any of the various kinds of walls which may enter into the construction of a building.

The formulas are simple, easy to understand, and easy to apply. English units are used in all the formulas and tables. The translation into English units of the quantities which enter into the formulas and tables has involved considerable labor, but every effort has been made to avoid mistakes. The calculations were in most cases checked by a second person after they were made by the author.

The author hopes that the work will prove of value to those who have to design or arrange heating and ventilating plants, and that it will direct attention to the vast amount of good work which has been done in recent years by German engineers in heating and ventilation.

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TABLE OF CONTENTS.

TABLES.

FORMULAS AND TABLES FOR HEATING.

I.—INTRODUCTION.

The subject of heating and ventilating buildings has received a great deal of attention in Germany during the past years, and scientists and engineers alike have devoted time and thought to it. The scientists have been spending much time determining the proper formulas and methods to be used in designing heating and ventilating plants, and the engineers have been tesing these formulas and methods by applying them to practical problems. The amount of work that has been done, in the way of gathering data and formulating rules for designing, is something surprising. And all of it has been done in that thorough, painstaking way that characterizes most of the work done by German scientists.

As an evidence of the great interest in subjects relating to heating and ventilating that is shown in Germany, it may be stated that two papers, the *Zeitschrift für Heizungs-, Lüftungs-, und Wasserleitungstechnik*, and the *Zeitschrift für Lüftung und Heizung*, both devoted to these subjects exclusively, are published there, and that one other, the *Gesundheits-Ingenieur*, pays a great deal of attention to them. Engineers and professors of the different technical schools are constantly contributing valuable articles to these papers.

The work that has been done in Germany is largely a continuation of the work that was done by Peclét in

France, and to-day represents the best and most modern scientific work in connection with heating and ventilating. Peclét's work became well known to English and American writers and engineers through Box's "Treatise on Heat," which consists very largely of translations from Peclét's "Traité de la Chaleur," and almost all English and American writers since Box's time have followed his lead, and have used Peclét's work alone as the basis of their writings, ignoring entirely the work done in Germany. Hence the work that has been done in Germany is almost unknown in this country except to those who can read German and who are, therefore, able to keep up with the German literature on heating and ventilating.

Knowing the value of the German work, the writer has undertaken to translate some of it for the benefit of the readers of *The Metal Worker;* and in order that the work may not occupy too much space, and to confine it to that which is of most importance to those who have to design or erect heating plants, the ground covered is, principally, the determination of the radiation surface required by different systems of heating to supply the heat lost through walls of different kinds.

The books which have been consulted in order to obtain the information that is given in the subsequent pages are: "Theoretische Maschinenlehre," by Dr. F. Grashof; "Leitfaden zum Berechnen und Entwerfen von Lüftungs- und Heizungs-Anlagen," by Prof. H. Rietschel; "Kalender für Heizungs-, Lüftungs-, und Badetechniker," by J. H. Klinger; "Kalender für Gesundheits Techniker," by H. Rechnagel; the files of the *Zeitschrift für Heizungs-, Lüftungs-, und Wasserleitungstechnik*, and other books and papers that need not be mentioned.

English units are used throughout: temperatures

are in Fahrenheit degrees; areas are in square feet; and heat quantities are in British heat units—*i. e.*, the quantity of heat required to raise the temperature of 1 pound of water 1 degree F.

II.—TEMPERATURES.

In this country when we design a heating and ventilating system it is usually done upon the supposition that all of the rooms and halls are kept at a constant temperature of 70 degrees when it is 0 degrees outside, and we never think of the temperature of the unheated cellar or attic, because the heat lost through the floors into the cellar and that lost through the ceilings into the cold attic is not included in our heat losses. We simply determine the heat lost through the walls and windows of the rooms, and then use a factor of safety to cover those losses which we have ignored. Our way, of course, is the easiest and the shortest, but it is not nearly so exact, and it leaves much to be guessed at. In Germany the engineers assume an outside temperature of 4 degrees below zero, and calculate, as exactly as possible, all the various amounts of heat lost, and in doing so they take account of the temperature of each room. The temperature is not supposed to be the same for all the rooms and halls of a building, nor is it supposed to be the same for rooms of different buildings. The temperatures generally assumed to be maintained in the heated rooms of different buildings are given in Table I.

Table I.—Temperatures of Heated Rooms.

	Degrees.
Rooms in which the occupants are for the most part at rest:	
Living rooms, business rooms, court houses, offices, schools.	68
Lecture halls and auditoriums	61 to 64
Rooms used only as sleeping rooms	54 to 59
Bathrooms in dwellings	68 to 72
Sickrooms	72

	Degrees.
Rooms in which the occupants are undergoing bodily exertion:	
Workshops, gymnasiums, fencing halls, &c., in which the exertion is vigorous	50 to 59
Workshops in which the exertion is not vigorous	61 to 64
Rooms use as passage rooms, or occupied by people in street dress:	
Entrance halls, passages, corridors, vestibules, &c	54 to 59
Churches	50 to 54
Miscellaneous:	
Prisons for confinement of prisoners during the day	64
Prisons for confinement of prisoners during the night	50
Hothouses	77
Cooling houses	59
Bathhouses:	
Swimming halls	68
Treatment rooms, massage rooms	77
Steam bath	113
Warm air bath	122
Hot air bath	140

These temperatures are supposed to be measured at a distance of about 5 feet, or "head high," above the floor.

When determining the heat lost through floors, ceilings or walls, as the case may be, which separate heated rooms from cellars, attics or other parts of a building which are not heated at all, or are only partially heated, the German engineers usually assume that when the outside temperature is about 4 degrees below zero the temperatures in the unheated parts of heated buildings are as given in Table II.

Table II.—Temperatures of Rooms Not Heated.

	Degrees.
Cellars and rooms kept closed	32
Rooms often in communication with the outside air, such as passages, entrance halls, vestibules, &c	23
Attic rooms immediately beneath metal or slate roof	14
Attic rooms immediately beneath tile, cement, or tar and gravel roof	23

III.—THE HEAT REQUIRED PER HOUR.

When calculating the total heat required per hour to maintain a room at a certain temperature the Ger-

man engineers are very careful to determine as nearly as possible the amount of heat that is evolved by the lights in the room, that given out by the occupants of the room when they are numerous, that which is carried away by the air supplied for ventilation, and that which is lost through the walls, windows, floor and ceiling.

The sum obtained by adding the heat carried off by the air supplied for ventilation to that lost through the walls, windows, floor and ceiling is the gross amount of heat required by the room per hour. And in order to get the net amount of heat required to maintain a constant temperature in the room there must be subtracted from the gross amount the sum obtained by adding the heat supplied by the lights to that supplied by the occupants of the room. When the amount of heat evolved by the lights and the occupants is small, as it always is except in assembly halls, auditoriums, theaters, &c., the amount of heat required per hour is equal to that carried away by the air for ventilation plus that lost through the walls, windows, floor and ceiling.

IV.—THE HEAT EVOLVED BY LIGHTS.

The amount of heat evolved by the lights in a room depends upon the kind and number of lights, and, when the light is the result of a combustion, upon whether or not the products of combustion escape into the room and mix with the air. The only lights which have usually to be considered are electric lights and gas lights. And as the amount of heat evolved per candle power per hour by either arc or incandescent electric lights is very small, the heat evolved by them is usually

neglected. The heat evolved by a gas light depends simply upon the heating power per cubic foot of the gas and upon the number of cubic feet of gas used per hour. The German engineers assume a heating power of illuminating gas of about 675 heat units per cubic foot. So that if the number of cubic feet of gas used per hour is multiplied by 675 the product is the number of heat units evolved by the gas lights per hour.

Example I.—What is the heat generated per hour by 20 gas lights, each burning 5 cubic feet of gas per hour?

The number of cubic feet of gas burned per hour is $20 \times 5 = 100$, and the heat evolved is $100 \times 675 = 67{,}500$ heat units.

In Table III is given the number of units of heat evolved per candle power per hour for different kinds of lights according to Rubner.

Table III.—Heat Evolved per Candle Power per Hour.

Kind of light.	Heat units.
Gas, ordinary split burner	300
Gas, Argand burner	200
Gas, Auer* burner	31
Petroleum	160
Electric, incandescent	14
Electric, arc	4.3

* This is a burner with a mantle; it resembles the Welsbach burner very much.

Example II.—What is the heat evolved per hour by 50 electric incandescent lights, each of about 16 candle power?

The total candle power is $16 \times 50 = 800$, and as the heat evolved per hour per candle power is 14 heat units, from Table III, the total heat evolved per hour is $14 \times 800 = 11{,}200$ heat units.

V.—THE HEAT EVOLVED BY THE OCCUPANTS.

The number of heat units given off by a person depends upon his age and state of rest, upon his clothing and upon the temperature of the surrounding air. Table IV gives the heat evolved per hour by different persons under different conditions.

Table IV.—Heat Given off by Persons in an Atmosphere of Medium Temperature.

Person.	Authority.	Heat units.
Suckling infant	Rubner.	63
Adult at rest	Rubner.	380
Adult at medium hard work	Rubner.	470
Adult at hard work	Rubner.	550
Adult in old age	Rubner.	360
Child, six years old	Barrel.	240
Man, 29 years old, in an atmosphere whose temperature is 31 degrees	Barrel.	610
The same, in an atmosphere whose temperature is 68 degrees	Barrel.	440
Man, 59 years old	Barrel.	510
Woman, 32 years old	Barrel.	480

According to Pettenkofer, the mean amount of heat given off per hour per person in an atmosphere at about 70 degrees is about 400 heat units for adults and 200 for children, and these are the amounts usually assumed when the heating effect of the occupants of assembly halls or auditoriums is taken into account.

VI.—THE HEAT CARRIED OFF BY THE AIR SUPPLIED FOR VENTILATION.

The amount of heat carried off by the air supplied for ventilation depends upon the amount of air supplied to the room per hour, and upon its entering and leaving temperatures. And the amount of air supplied per hour depends upon the sources of contamination of the air and the degree of purity which it is desired shall be preserved.

In Table V, from Rietschel, are given the amounts of air to be supplied to different rooms per hour when the air is not contaminated by the products of combustion from gas lights.

Table V.—Amount of Air to be Supplied to Rooms per Hour.

	Cubic feet per occupant.
Sickrooms for adults	2,600
Sickrooms for children	1,200
Schoolrooms for children under 10 years old	350 to 600
Schoolrooms for children over 10 years old	575 to 1,000
Auditoriums and assembly halls	600 to 1,100
Theaters, concert and festival halls	900 to 1,100
Prisons and barracks	700 to 1,100
Public exchanges	525 to 700
Workshops for vigorous work	600 to 1,100
Workshops for light work	700 cubic feet per occupant to twice the volume of the room.
Living rooms	one to two times the volume of the room.
Stairways and halls much used	three to four times the volume of the room.
Stairways and halls not much used	one-half to one time the volume of the room.
Kitchens and privies	three to five times the volume of the room.

It is interesting to compare the values in Table V with those in Table V*a*, which are taken from *Grundzüge der Hygiene*, by Dr. W. Prausnitz.

Table Va.—Amount of Air to be Supplied to Rooms.

	Cubic feet per hour per occupant.
Living rooms	1,800
Hospitals for ordinary sickness	2,100 to 2,500
Hospitals for wounded, and lying-in institutions	3,500
Hospitals for epidemical diseases	5,300
Workshops, the ordinary kind	2,100
Workshops with special sources of contaminations of the air	3,500
Barracks, during the day	1,100
Barracks, during the night	1,400 to 1,800
Theaters	1,400 to 1,800
Assembly rooms, during long meetings	2,100
Assembly rooms, during short meetings	1,400
Free schools	425 to 525
[illegible]s for adults	900 to 1,100

It is impossible to help contrasting the amount of air which is considered sufficient for pupils in Germany with the amount which we in this country usually provide. In this country it is customary to provide about 1800 cubic feet of air per hour for each pupil, whereas in Germany the maximum amount seems to be about 1100 cubic feet per hour per pupil.

The entering temperature of the air is usually taken as the minimum temperature of the outside air at which the ventilation is to be carried on, and this is usually assumed to be about 4 degrees below zero. The temperature of the air when it leaves the room is usually assumed to be about the same as the temperature in the room, and it is usually assumed that, at ordinary temperatures, 1 cubic foot of air will require 0.019 heat unit to raise its temperature 1 degree. So that if Q is the number of cubic feet of air supplied per hour for ventilation, t_0 the temperature of the air outside, and t_1 the temperature of the air in the room, as indicated by a thermometer about 4.5 or 5 feet above the floor, the heat, H_1, carried off by the air supplied for ventilation is $H_1 = 0.019\ Q\ (t_1 - t_0)$.

In this country it is usual to assume t_1 as 70 degrees and t_0 as 0 degrees, so that for this country the expression for H_1 becomes

$$H_1 = 0.019Q\ (70-0) = 1.33Q = \frac{4Q}{3}.$$

Example III.—A hall will seat 2000 people. It is lighted by 200 gas lights, each burning 4 cubic feet of gas per hour, and 1500 cubic feet of air are supplied per hour per person for ventilation.

Determine: *a*, the heat evolved per hour by the people; *b*, the heat evolved per hour by the lights; *c*, the heat carried off by the air supplied for ventilation,

when the room is kept at a temperature of 60 degrees and the temperature of the air outside is 20 degrees.

a. As each adult will evolve 400 units of heat per hour, the heat evolved by 2000 people per hour, supposing ail to be adults, is $400 \times 2000 = 800,000$ heat units.

b. The number of cubic feet of gas burned per hour is $4 \times 200 = 800$. And as each cubic foot of gas will evolve about 675 units of heat when burned, the total heat evolved per hour by the gas is $800 \times 675 = 540,000$ heat units.

c. The total number of cubic feet of air supplied per hour is $2000 \times 1500 = 3,000,000$. In this case t_1 is 60, t_0 is 20, and $t_1 - t_0$ is 40. Therefore from the equation for H_1, we have $H_1 = 0.019 \times 3,000,000 \times 40 = 2,280,000$ heat units.

VII.—THE TRANSMISSION OF HEAT THROUGH WALLS.

In all problems relating to the heating of a building we have to deal with the question of the transmis-

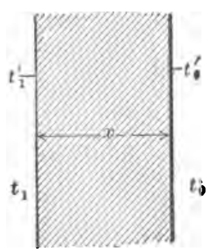

Fig. 1.

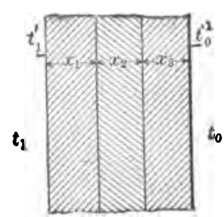

Fig. 2.

sion of heat from a mass of hot air through a wall of brick, stone, wood or glass to a mass of cold air on the other side of the wall. The wall may be made of a

single layer of material, as shown in Fig. 1, or it may be made up of several layers of different materials in contact with one another, as shown in Fig. 2, or it may be made up of two or more layers of materials separated from one another by an air space, as shown in Fig. 3.

The simple wall shown in Fig. 1 presents the simplest problem, while the walls shown in Figs. 2 and 3 always present rather difficult problems. The layers in both Fig. 2 and Fig 3 may be of the same or different thicknesses.

In all cases, however, the transmission of heat

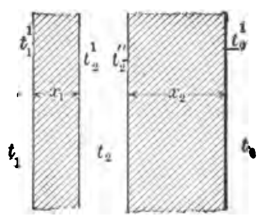

Fig 3.

through the wall from the warm air, whose temperature is t_1, to the cold air, whose temperature is t_0, goes on in exactly the same way. In the case of a single wall, as shown in Fig. 1, the heat passes by radiation and conduction from the warm bodies and air, whose temperature is t_1, to the surface of the wall, whose temperature is t'_1 ; then, by conduction, it passes from particle to particle through the wall to the surface on the other side, whose temperature is t'_0 ; then, by radiation and conduction, it passes from this surface to the air in contact with it, whose temperature is t_0.

In the case of a wall made up of layers without air spaces, as shown in Fig. 2, the heat passes from layer to layer by conduction; and in the case of a wall with an air space between two layers, as shown in Fig. 3, the heat passes through each layer as if it were a single wall.

Since heat will pass only from a warmer body to a cooler one, it follows that the temperature, t'_1, of the inside surface of the wall is less than the temperature, t_1, of the warm air; and that the temperature, t'_0, of the outside surface is greater than the temperature, t_0, of the cold air. It also follows that there is a continual decrease of temperature of the particles from the inside surface of the wall or layer to the outside surface.

After everything has gotten in a stable condition the amount of heat which passes per hour through the inside surface, the outside surface, or any layer of the wall, must always be the same. And hence, if we could calculate the amount of heat that passed per hour through the inside surface or any layer of the wall we would have the amount of heat which passed per hour through the wall. It has been determined as a result of experiments that the amount of heat which will pass per hour to or from 1 square foot of the surface of a wall is equal to the difference between the temperature of the air and that of the surface of the wall multiplied by a certain factor, which depends upon the nature of the material of the wall and the condition of rest or motion of the air. Therefore the quantity of heat which passes per hour from the warm air to 1 square foot of the surfaces of the walls shown in Figs. 1, 2 and 3 may be expressed as $a_1\ (t_1 - t'_1)$; and the heat which passes per hour from each square foot of the outside surfaces may be expressed as $a_0\ (t'_0 - t_0)$.

If the wall has an air space, as shown in Fig. 3, the heat which passes per hour from each square foot of the surface of the left hand layer to the air, whose temperature is t_2, in the air space may be expressed as $a^1_1 (t^1_2 - t_2)$, and the heat which passes per hour from the air to each square foot of the surface of the right hand layer may be expressed as $a^1_0 (t_2 - t^{11}_2)$. It is evident from what has been said, that for the same wall these quantities are equal to one another, and we have $a_1 (t_1 - t^1_1) = a_0 (t^1_0 - t_0)$, for a wall without an air space, and $a_1 (t_1 - t^1_1) = a^1_1 (t^1_2 - t_2) = a^1_0 (t_2 - t^{11}_2) = a_0 (t^1_0 - t_0)$ for a wall with one air space.

We also know, from the results of experiments, that the amount of heat which passes per hour through a wall whose thickness is x and whose surfaces have an area of 1 square foot is equal to the difference between the temperatures of the surfaces multiplied by a certain factor, e, called the coefficient of conductivity, and divided by the thickness of the wall. Therefore, the heat which passes per hour through the wall in Fig. 1 for each square foot of its surface is

$$\frac{e}{x} (t^1_1 - t^1_0),$$

and the amounts which pass through the left hand and right hand layers of the wall in Fig. 3 are

$$\frac{e_1}{x_1} (t^1_1 - t^1_2)$$

and

$$\frac{e_2}{x_2} (t^{11}_2 - t^1_0),$$

respectively. If the two layers of the wall in Fig. 3 were made of the same materials e_1 would be equal to e_2.

We cannot use any one of the expressions which have been given above to determine the amount of

heat which passes through the wall per hour, because we do not know the temperature of either surface of the wall. If we knew the temperature of either the inside or the outside surface we could at once determine the heat which passes through 1 square foot of the wall per hour, but we know only the temperature, t_1, of the inside air and that, t_0, of the outside air. Hence we say, let the heat which is transmitted through the wall per hour per square foot of surface be $k\,(t_1 - t_0)$, where k is a factor to be determined for each wall. And since the amount of heat which passes through the whole wall is equal to that which passes through the inside or through either surface, we have

$$k\,(t_1-t_0)=a_1\,(t_1-t^1{}_1)=a_0\,(t^1{}_0-t_0)=\frac{e}{x}\,(t^1{}_1-t^1{}_0)$$

for a simple wall; and

$$k\,(t_1-t_0)=a_1\,(t_1-t^1{}_1)=a^1{}_1\,(t^1{}_2-t_2)=a^1{}_0\,(t_2-t^{11}{}_2)=a_0\,(t^1{}_0-t_0)$$
$$=\frac{e_1}{x_1}\,(t^1{}_1-t^1{}_2)=\frac{e_2}{x_2}\,(t^{11}{}_2-t^1{}_0)$$

for a wall with an air space.

By an algebraic process,* which would be out of

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* **The derivation of the expression for k for a simple wall is as follows:**

$$a_1\,(t_1-t^1{}_1)=k\,(t_1-t_0);$$
$$a_0\,(t^1{}_0-t_0)=k\,(t_1-t_0);$$
$$\frac{e}{x}\,(t^1{}_1-t^1{}_0)=k\,(t_1-t_0).$$

From these we get

$$t_1-t^1{}_1=\frac{k}{a_1}\,(t_1-t_0);$$
$$t^1{}_0-t_0=\frac{k}{a_0}\,(t_1-t_0);$$
$$t^1{}_1-t^1{}_0=\frac{xk}{e}\,(t_1-t_0).$$

Add, and divide by t_1-t_0 and we get

$$1=k\left(\frac{1}{a_1}+\frac{1}{a_0}+\frac{x}{e}\right).$$

From which

$$k=\frac{1}{\frac{1}{a_1}+\frac{1}{a_0}+\frac{x}{e}}.$$

place here, it may be shown that

$$k=\frac{1}{\frac{1}{a_1}+\frac{1}{a_0}+\frac{x}{e}}$$

for a simple wall, as shown in Fig. 1

$$k=\frac{1}{\frac{1}{a_1}+\frac{1}{a_0}+\frac{x_1}{e_1}+\frac{x_2}{e_2}+\frac{x_3}{e_3}}$$

for a wall composed of layers of different materials, as shown in Fig. 2;

$$k=\frac{1}{\frac{1}{a_1}+\frac{1}{a^1_1}+\frac{1}{a^1_1}+\frac{1}{a_0}+\frac{x_1}{e_1}+\frac{x_2}{e_2}}$$

for a wall with one air space, as shown in Fig. 3.

For thin glass or metal walls $\frac{x}{e}$ is usually so small that we may omit it, and the expression for k becomes

$$k=\frac{1}{\frac{1}{a_1}+\frac{1}{a_0}}.$$

VIII.—HOW TO DETERMINE k.

In order to determine the value of k for a wall, it is necessary that we know or be able to determine the values of a_1, a_0 and e for the wall, or for each part of the wall if it be made up of layers.

$\frac{1}{a_1}$ represents the resistance to the transmission of heat from the warm air and the objects in the room to the inside surface of the wall; $\frac{1}{a_0}$ repoesents the resistance to the transmission of heat from the outside surface; and $\frac{x}{e}$ represents the resistance to the passage of heat through the wall.

The expressions for k for walls built up of layers of materials, with or without air spaces, are deduced in the same way as the expression for k for a simple wall.

a_1 and a_0 are dependent upon the material of which the wall is made, upon the condition of the surface, to a slight extent, and the condition of rest or motion of the air in contact with the surface. Grashof gives the following equation for calculating the values of a_1 and a_0:

$$a_1 \text{ or } a_0 = c + d + \frac{(40\,c + 30\,d)\,T}{10000}.$$

c is a factor whose value depends upon the condition of rest or motion of the air. The values used by Rietschel are given in Table VI.

d is a factor whose value depends upon the material of the wall, and to a slight extent upon the condition of the surface. The values of d for different materials are given in Table VII.

T represents the difference between the temperature of the air and that of the surface of the wall. For thick walls and poor conductors this difference is so small that it is called zero in calculating a_1 or a_0, although it can never become exactly zero. For rough work T may usually be taken as zero without much effect upon the value of k, which is obtained from a_1 and a_0. For an outside temperature of about 4 degrees below zero, and an inside temperature of about 68 degrees, Rietschel uses the values of T which are given in Table VIII, although they are probably smaller than the actual values. T for a thin metal or glass wall, is equal to ½ $(t_1 - t_0)$.

Table VI.—Values of c.

	c.
Air at rest, air in rooms in contact with walls	0.82
Air with slow motion, air in rooms in contact with cold windows...	1.03
Air with quick motion, air outside of building	1.23

Table VII.—Values of d.

Substance.	*d.*	*Substance*	*d.*
Brick work	0.74	Iron, rusted	0.69
Mortar	0.74	Cast iron, new	0.65
Plaster of Paris	0.74	Sheet iron, usual condition	0.57
Stone masonry	0.74	Sheet iron, polished	0.092
Wood	0.74	Sheet iron covered with lead	0.13
Paper	0.78	Brass, polished	0.053
Glass	0.60	Copper	0.033
Glass with wet surface	1.09	Tin	0.045
		Zinc	0.049

Table VIII.—Values of T Used by Rietschel.

	T.
For brick work about 5 inches thick	14.4
For brick work about 10 inches thick	12.6
For brick work about 15 inches thick	10.8
For brick work about 20 inches thick	9.0
For brick work about 25 inches thick	7.2
For brick work about 30 inches thick	5.4
For brick work about 35 inches thick	3.6
For brick work about 40 inches thick	1.8
For brick work thicker than 45 inches	0.0
For single windows	36.0
For double windows	18.0
For wooden doors	1.8
For partition walls	0.0

Example IV.—Determine $\frac{1}{a_1}$ and $\frac{1}{a_0}$ for a brick wall 9 inches thick.

From Table VI we find that c is 0.82 for the inside surface and 1.23 for the outside surface. From Table VII we find that d is 0.74, and from Table VIII we find that T is about 13. Therefore we have

$$a_1=0.82+0.74+\frac{(0.82\times 40+0.74\times 30)13}{10000}=0.82+0.74+0.07=1.63,$$

and

$$a_0=1.23+0.74+\frac{(1.23\times 40+0.74\times 30)13}{10000}=1.23+0.74+0.09=2.06.$$

Then

$$\frac{1}{a_1}=\frac{1}{1.63}=0.614$$

and

$$\frac{1}{a_0}=\frac{1}{2.06}=0.485.$$

If we had omitted that part of a_1 and a_0 which involved T, we would then have had

$$a_1=0.82+0.74=1.56\,;$$
$$a_0=1.23+0.74=1.97\,;$$
$$\frac{1}{a_1}=\frac{1}{1.56}=0.642,$$

and

$$\frac{1}{a_0}=\frac{1}{1.97}=0.508.$$

Example V.—Determine $\frac{1}{a_1}$ and $\frac{1}{a_0}$ for a single window.

From Table VI we find that c is 1.03 for the inside surface and 1.23 for the outside. From Table VII we find that d is 0.59, and from Table VIII we find that T is 36. Therefore we have

$$a_1=1.03+0.59+\frac{(1.03\times40+0.59\times30)\ 36}{10000}=1.03+0.59+0.21=1.83\,;$$
$$a_0=1.23+0.59+\frac{(1.23\times40+0.59\times30)\ 36}{10000}=1.23+0.59+0.24=2.06\,;$$
$$\frac{1}{a_1}=\frac{1}{1.83}=0.546;$$

and

$$\frac{1}{a_0}=\frac{1}{2.06}=0.485.$$

For brick walls Recknagel makes a_1 equal to 1.23, and makes the value of a_0 depend upon the velocity of the air, as shown in Table IX.

Table IX.—Recknagel's Values of a_0 for Brick Walls.

Velocity of the air at a distance of 1.5 feet from the surface of the wall.		
Feet per second.	Miles per hour.	Value of a_0.
0.0	0.0	1.23
3.3	2.25	4.20
14.8	10.0	6.15
18.0	12.3	7.40

As, however, Recknagel does not say how or where he gets the values of a_0 given in the table, it is probably best not to use them.

After we have determined the values of $\frac{1}{a_1}$ and $\frac{1}{a_0}$. it is necessary to determine the value of $\frac{x}{e}$ in order to determine k. The thickness of the wall or each layer must be determined from the wall, or a drawing of it, and must always be given in inches. The value of e depends upon the material of which the wall or layer is made and must be determined by experiments. In Table X are given the values of e for those materials which we have to deal with in heating work; but no values are given for metals, because metals are seldom used as walls of a building, and when they are they are so thin that the value of $\frac{x}{e}$ is so small that it may be neglected in determining the value of k. Again, there seems to be a great difference in the values of e for the same metal as determined by different experiments and as given by different writers.*

Table X.—Values of e for Different Materials.

Material.	e.
Brick work	5.6
Mortar, plaster	5.6
Plaster of paris	3.7
Rubble masonry	14
Limestone	15
Marble, fine grained	28
Marble, coarse grained	22
Oak, across the grain	1.71
Pine, with the grain	1.4

* In Table Xa are some of the values of e for different metals. Those in the column marked Z are taken from the *Zeitschrift des Vereins Deutscher Engintieure*, Vol. XXXX, No. 2, January, 1896; and those in the column marked R are taken from *Rietschel's Leitfaden zum Berechnen und Entwerfen von Lüftungs-und Heizungs-Anlagen.*

Pine, across the grain	0.76
Sandstone	10
Glass	6.6
Paper	0.27

Table Xa.

Metal.	Values of *e*. Z.	R.
Brass	660	300
Copper	2,660	520
Iron	450	190
Lead	230	105
Tin	440	137
Zinc	850	145

To find k for a simple wall we determine the values of

$$\frac{1}{a_1},\ \frac{1}{a_0} \text{ and } \frac{x}{e},$$

and put these values in the equation

$$k=\frac{1}{\frac{1}{a_1}+\frac{1}{a_0}+\frac{x}{e}}.$$

Example VI.—What is k for a 13-inch brick wall, as shown in Fig. 4 ?

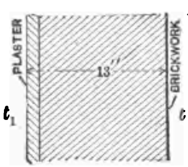

Fig. 4.

We first find a_1 and a_0 by the expression

$$a_1 \text{ or } a_0=c+d+\frac{(40\,c+30\,d)\,T}{10000}.$$

From Table VI, c is 0.82 for a_1 and 1.23 for a_0; d,

from Table VII, is 0.74, and T, from Table VIII, is about 12. Therefore

$$a_1 = 0.82 + 0.74 + \frac{(40 \times 0.82 + 30 \times 0.74)\ 12}{10000} = 1.63\ ;$$

$$a_0 = 1.23 + 0.74 + \frac{(40 \times 1.23 + 30 \times 0.74)\ 12}{10000} = 2.06.$$

$$\frac{1}{a_1} = \frac{1}{1.63} = 0.614,$$

and

$$\frac{1}{a_0} = \frac{1}{2.06} = 0.485.$$

From Table X, e is 5.6 for brick work and plaster, and, therefore,

$$\frac{x}{e} = \frac{13}{5.6} = 2.32.$$

Hence

$$k = \frac{1}{\frac{1}{a_1} + \frac{1}{a_0} + \frac{x}{e}} = \frac{1}{0.614 + 0.485 + 2.32} = \frac{1}{3.42} = 0.292.$$

It is interesting to note the small difference between the value of k, obtained above, and the value that would be obtained if T is taken as equal to zero, so that the expressions for a_1 and a_0 would become

$$a_1 = 0.82 + 0.74 = 1.56\ ;$$

$$a_0 = 1.23 + 0.74 = 1.97.$$

$$\frac{1}{a_1} = \frac{1}{1.56} = 0.642\ ;$$

and

$$\frac{1}{a_0} = \frac{1}{1.97} = 0.508.$$

The values of e and $\frac{x}{e}$ would remain unchanged, so that we would have

$$k = \frac{1}{\frac{1}{a_1} + \frac{1}{a_0} + \frac{x}{e}} = \frac{1}{0.642 + 0.508 + 2.32} = 0.288.$$

The difference between this value of k and that obtained by the former method is so small that it would appear to be unworthy of notice, especially as we would take k as equal to 0.29 in either case. But the Germans do not neglect even the little things; they work everything out as exactly as possible, and then, if it is necessary, use a factor of safety.

Example VII.—What is k for a 13-inch wall with a 4-inch layer of limestone on the front, as shown in Fig. 5?

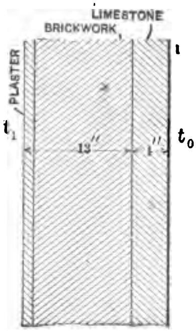

Fig. 5.

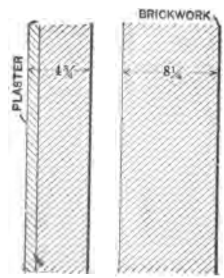

Fig. 6.

Here we have a wall with two exposed surfaces in contact with air, but made up of brick and stone. For a wall of this kind we have

$$k = \frac{1}{\frac{1}{a_1} + \frac{1}{a_0} + \frac{x_1}{e_1} + \frac{x_2}{e_2}}.$$

From Table VI we find, as before, c is 0.82 for the inside and 1.23 for the outside; from Table VII, d is 0.74; and, since the whole thickness of the wall is 17

inches, we may take T, from Table VIII, as 10. Therefore we have

$$a_1 = 0.82 + 0.74 + \frac{(40 \times 0.82 + 30 \times 0.74)\ 10}{10000} = 1.62;$$

$$a_0 = 1.23 + 0.74 + \frac{(40 \times 1.23 + 30 \times 0.74)\ 10}{10000} = 2.04;$$

$$\frac{1}{a_1} = \frac{1}{1.62} = 0.617;$$

$$\frac{1}{a_0} = \frac{1}{2.04} = 0.490.$$

From Table X we find that e is 5.6 for brick work and mortar, and 15 for limestone; and hence

$$\frac{x_1}{e_1} = \frac{13}{5.6} = 2.32;$$

$$\frac{x_2}{e_2} = \frac{4}{15} = 0.267.$$

Therefore we have

$$k = \frac{1}{\frac{1}{a_1} + \frac{1}{a_0} + \frac{x_1}{e_1} + \frac{x_2}{e_2}} = \frac{1}{0.617 + 0.490 + 2.32 + 0.267} = \frac{1}{3.69} = 0.271.$$

Example VIII.—What is k for a 13-inch wall with an air space, as shown in Fig. 6?

Here we have a wall with four surfaces in contact with air, and for a wall of this kind, as has been explained before, we have

$$k = \frac{1}{\frac{1}{a_1} + \frac{1}{a^1_1} + \frac{1}{a^1_0} + \frac{1}{a_0} + \frac{x_1}{e_1} + \frac{x_2}{e_2}}.$$

a^1_1 and a^1_0 are for the surfaces in contact with the air in the air space, whose temperature is t_3. In calculating k for such a wall Rietschel assumes that a_1, a^1_1 and a^1_0 are equal, and in calculating them and a_0 he uses the same value of T that he would use for a wall of the same total thickness of brick work but without

the air space. As before, from Tables VI, VII and VIII, we have

$$a_1 = a^1_1 = a^1_0 = 0.82 + 0.74 + \frac{(40 \times 0.82 + 30 \times 0.74)\ 10}{10000} = 1.62;$$

$$a_0 = 1.23 + 0.74 + \frac{(40 \times 1.23 + 30 \times 0.74)\ 10}{10000} = 2.04;$$

$$\frac{1}{a_1} = \frac{1}{a^1_1} = \frac{1}{a^1_0} = \frac{1}{1.62} = 0.62;$$

and

$$\frac{1}{a_0} = \frac{1}{2.04} = 0.49.$$

Since the left hand and the right hand parts of the wall are both made of brick work, we have, from Table X, $e_1 = e_2 = 5.6$; and hence

$$\frac{x_1}{e_1} = \frac{4.75}{5.6} = 0.85;$$

$$\frac{x_2}{e_2} = \frac{8.25}{5.6} = 1.47.$$

Put these values in the expression for k, and we have

$$k = \frac{1}{\frac{1}{a_1} + \frac{1}{a^1_1} + \frac{1}{a^1_0} + \frac{1}{a_0} + \frac{x_1}{e_1} + \frac{x_2}{e_2}} = \frac{1}{0.62 + 0.62 + 0.62 + 0.49 + 0.85 + 1.47}$$
$$= \frac{1}{4.67} = 0.214.$$

It may be interesting to note that if, in calculating a_1, a^1_1, a^1_0 and a_0, we had neglected T entirely, we would have had the following:

$$a_1 = a^1_1 = a^1_0 = 0.82 + 0.74 = 1.56;$$

$$a_0 = 1.23 + 0.74 = 1.97;$$

$$\frac{1}{a_1} = \frac{1}{a^1_1} = \frac{1}{a^1_0} = \frac{1}{1.56} = 0.64;$$

and

$$\frac{1}{a_0} = \frac{1}{1.97} = 0.51.$$

$$k=\frac{1}{\frac{1}{a_1}+\frac{1}{a'_1}+\frac{1}{a'_0}+\frac{1}{a_0}+\frac{x_1}{e_1}+\frac{x_2}{e_2}}=\frac{1}{0.64+0.64+0.64+0.51+0.85+1.47}$$

$$=\frac{1}{4.75}=0.210.$$

Example IX.—What is k for a window, Fig. 7, having ordinary glass of single thickness ?

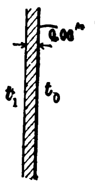

Fig. 7.

Here, as for a single wall, we have

$$k=\frac{1}{\frac{1}{a_1}+\frac{1}{a_0}+\frac{x}{e}}.$$

From Table VI, c is 1.03 for the inside surface and 1.23 for the outside; from Table VII, d is 0.60; and, from Table VIII, T is 36. Hence

$$a_1=1.03+0.60+\frac{(40\times 1.03+30\times 0.60)\ 36}{10000}=1.03+0.60+0.21=1.84\ ;$$

$$a_0=1.23+0.60+\frac{(40\times 1.23+30\times 0.60)\ 36}{10000}=1.23+0.60+0.24=2.07\ ;$$

$$\frac{1}{a_1}=\frac{1}{1.84}=0.54;$$

and

$$\frac{1}{a_0}=\frac{1}{2.07}=0.48.$$

From Table X, e is 6.6. Hence, if we assume the thickness of the glass to be 0.06 inch, we have

$$\frac{x}{e}=\frac{0.06}{6.6}=0.009,$$

or, say, 0.01, a quantity so small that it may be neglected without much error.

$$k=\frac{1}{\frac{1}{a_1}+\frac{1}{a_0}+\frac{1}{e}}=\frac{1}{0.54+0.48+0.01}=\frac{1}{1.03}=0.97.$$

If it be assumed that there is water condensed on the inside, so that the surface is covered with water, d for a_1 is, from Table VII, 1.09, and we get

$$a_1=1.03+1.09=\frac{(40\times1.03+30\times1.09)}{10000}\frac{36}{}=1.03+1.09+0.27=2.39\,;$$

and

$$\frac{1}{a_1}=\frac{1}{2.39}=0.42.$$

This value of $\frac{1}{a_1}$ in the expression for k gives

$$k=\frac{1}{0.42+0.48+0.01}=\frac{1}{0.91}=1.10.$$

Example X.—What is k for a double window, Fig. 8, with glass of single thickness?

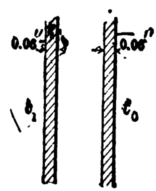

Fig. 8.

Here we have two walls of glass with an air space between, and the expression for k is

$$k=\frac{1}{\frac{1}{a_1}+\frac{1}{a^1_1}+\frac{1}{a^1_0}+\frac{1}{a_0}+\frac{x_1}{e_1}+\frac{x_2}{e_2}}.$$

There are really two cases to this problem: 1, When the inner window is tight, so that the air from

the inside cannot come in contact with the outer window and deposit its moisture on it, all the surfaces are dry; and, 2, when there is a deposit of moisture on the inner surface of the outer wall.

In either case it is customary to take c as 0.82 for the inside surface of the inside glass, and as 1.03 for the surfaces in contact with the air between the windows; and to take T as 18 when calculating a_1, a^1_1, a^1_0 and a_0.

First Case.—All surfaces dry.

$$a_1=0.82+0.60+\frac{(40\times 0.82+30\times 0.6)\ 18}{10000}=0.82+0.60+0.09=1.51;$$

$$a^1_1=a^1_0=1.03+0.6+\frac{(40\times 1.03+30\times 0.60)\ 18}{10000}=1.03+0.60+0.11=1.74;$$

$$a_0=1.23+0.60+\frac{(40\times 1.03+30\times 0.60)\ 18}{10000}=1.23+0.60+0.12=1.95;$$

$$\frac{1}{a_1}=\frac{1}{1.51}=0.66;$$

$$\frac{1}{a^1_1}=\frac{1}{a^1_0}=\frac{1}{1.74}=0.58;$$

$$\frac{1}{a_0}=\frac{1}{1.95}=0.51;$$

$$\frac{x_1}{e_1}=\frac{x_2}{e_2}=\frac{0.06}{0.6}=0.01,$$

as in the previous example.

$$k=\frac{1}{\frac{1}{a_1}+\frac{1}{a^1_1}+\frac{1}{a^1_0}+\frac{1}{a_0}+\frac{x_1}{e_1}+\frac{x_2}{e_2}}=\frac{1}{0.66+0.58+0.58+0.51+0.01+0.01}$$

$$=\frac{1}{2.35}=0.43.$$

Second Case.—The inside surface of the outer glass wet with water condensed from the air between the two glasses.

$$a_1,\ a^1_1,\ a_0,\ \frac{x_1}{e_1} \text{ and } \frac{x_2}{e_2}$$

are the same in this case as in the first case, but a^1_0 is

different. In calculating a'_0 we take d as 1.09, as given in Table VII for glass with wet surface. Therefore we have

$$\frac{1}{a_1}=0.66\,;$$

$$\frac{1}{a'_1}=0.58\,;$$

$$\frac{1}{a_0}=0.51\,;$$

$$\frac{x_1}{e_1}=0.01\,;$$

and

$$\frac{x_2}{e_2}=0.01.$$

For a'_0 we have

$$a'_0=1.03+1.09+\frac{(40\times 1.03+30\times 1.09)\ 18}{10000}=1.03+1.09+0.13=2.25.$$

Hence

$$\frac{1}{a'_0}=\frac{1}{2.25}=0.44\,;$$

and

$$k=\frac{1}{0.66+0.58+0.44+0.51+0.01+0.01}=\frac{1}{2.21}=0.45.$$

IX.—HOW TO DETERMINE T.

As has been said, T is the difference between the temperature of the air and that of the surface of the wall in contact with it, and it is usually necessary to know T approximately in order to correctly calculate a_1, a_0 and k; but, as has also been shown, we may neglect T and calculate a_1, a_0 and k, and get results that will not differ much from the correct results. Rietschel does not say how he determines the values of

T given in Table VIII, but it is probable that he uses some such method as the following:

Let Fig. 9 represent a wall whose thickness is x. Let the temperature of the warm air be t_1; that of the left hand surface be t'_1; that of the right hand surface

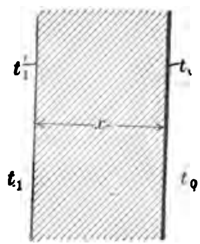

Fig. 9.

be t'_0; and that of the cold air be t_0. Then, as has been said before, we know that

$$a_1\,(t_1-t'_1)=k\,(t_1-t_0);$$

and

$$a_0\,(t'_0-t_0)=k\,(t_1-t_0).$$

From these we get

$$t_1-t'_1=\frac{k\,(t_1-t_0)}{a_1};\quad t'_0-t_0=\frac{k\,(t_1-t_0)}{a_0}.$$

Now neglect T, and find approximate values for a_1, a_0 and k; and then, by the equations above, determine $t_1-t'_1$ and t'_0-t_0. The smaller of these we may assume as T.

Example XI.—What is the value of T for a 13-inch brick wall when t_1 is 70 degrees and t_0 is 0 degrees?

If we neglect T we have

$$a_1=0.82+0.74=1.56;$$

$$a_0=1.23+0.74=1.97;$$

$$\frac{1}{a_1}=\frac{1}{1.56}=0.64;$$

$$\frac{1}{a_0}=\frac{1}{1.97}=0.51;$$

$$\frac{x}{e}=\frac{13}{5.6}=2.32.$$

$$k=\frac{1}{\frac{1}{a_1}+\frac{1}{a_0}+\frac{x}{e}}=\frac{1}{0.64+0.51+2.32}=\frac{1}{3.47}=0.29.$$

By the conditions of the problem we have

$$t_1-t_0=70-0=70;$$

and hence

$$t_1-t^1_1=\frac{k\,(t_1-t_0)}{a_1}=\frac{0.29\times 70}{1.56}=13;$$

and

$$t^1_0-t_0=\frac{k\,(t_1-t_0)}{a_0}=\frac{0.29\times 70}{1.97}=10.$$

Hence we assume T as equal to 10 for a wall about 13 inches thick.

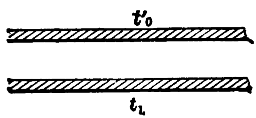

Fig. 10.

When determining T for the ceiling of a heated room, the German engineer will either assume the temperature of the air at the ceiling to be about 86

degrees, or he will calculate it by a formula which will be given later, and he will assume the temperature of the air in the room above to be as given in either Table I or Table II, depending upon whether or not it is heated. Thus, Rietschel, when calculating k for a skylight composed of two thicknesses of glass, as shown in Fig. 10, assumes that when the outside temperature is about 4 degrees below zero and the inside temperature is 68 degrees, the temperature of the air at the ceiling is about 86 degrees, and T is 22.5 degrees.

X.—SOME VALUES OF k.

In Tables XI, XII and XIII are given values for k for various walls.

Table XI is a translation of the greater part of a table giving those values of k which must be used in designing heating plants for State or Government buildings for the State of Prussia in Germany. The translation is made from a table given in Recknagel's Kalender für Gesundheit-Teckniker for 1897. These values for k, adopted by the Prussian authorities for use in connection with official buildings, are almost exactly the same as those given by Rietschel.

In Table XII are given values of k that have been obtained by interpolation from tables given by Rietschel and Recknagel.

In Table XIII are given values for k for those walls, floors, partitions, &c., that are used in this country but not in Germany. These values have been calculated by the author.

The thickness of the plastering and stuccoing must always be included in the thickness of a brick wall.

Table XI.—Values of k Adopted by the State of Prussia, Germany.

(A) Brick work:

Inches thick.	k	Inches thick.	k
4.72	0.492	30.3	0.164
9.85	0.348	35.4	0.133
15.0	0.266	40.5	0.123
20.1	0.226	45.6	0.113
25.2	0.184		

(B) Sandstone masonry, block or rubble:

Inches thick.	k	Inches thick.	k
11.8	0.451	31.5	0.266
15.7	0.390	35.4	0.246
19.7	0.348	39.4	0.226
23.8	0.318	43.3	0.205
27.6	0.287	47.2	0.195

The values of k for limestone masonry should be taken as about 10 per cent. greater than for sandstone masonry of the same thickness.

(C) Miscellaneous:

	k
Single window	1.02
Double window	0.472
Single skylight	1.09
Double skylight	0.492
Doors	0.410
Plaster from 1.6 to 2.6 inches thick, on wire lathing	0.615
Plaster from 2.6 to 3.2 inches thick, on wire lathing	0.492

Table XII.

(A) **Brick walls: Bricks are supposed to be 8¼ x 4 x 2 inches and laid with vertical mortar joints ⅜ inch thick. Plastering is supposed to be ¾ inch thick.**

Thickness of wall.	Outside walls. No plaster. k	Outside walls. One side plastered. k	Inside walls. Both sides plastered. k
½ brick	0.52	0.49	0.43
1 brick	0.37	0.36	0.33
1½ bricks	0.29	0.28	0.26
2 bricks	0.25	0.24	....
2½ bricks	0.22	0.21	....
3 bricks	0.19	0.18	....
3½ bricks	0.16	0.16	....
4 bricks	0.14	0.14	....
4½ bricks	0.12	0.12	....

(B) Brick walls with sandstone faces: Walls plastered on the inside.

Thickness of wall.	Thickness of stone face. 4 inches. k	8 inches. k	12 inches. k
1 brick	0.31	0.29	0.26
1½ bricks	0.25	0.23	0.21
2 bricks	0.22	0.20	0.19
2½ bricks	0.19	0.18	0.17
3 bricks	0.17	0.16	0.15
3½ bricks	0.15	0.14	0.13

(C) Brick walls, each with an air space of about 2.4 inches: Walls plastered on the inside.

Thickness of wall.	k	Thickness of wall.	k
1 brick	0.25	3 bricks	0.14
1½ bricks	0.21	3½ bricks	0.13
2 bricks	0.19	4 bricks	0.12
2½ bricks	0.16		

(D) Brick walls, with "plaster board"* 1.18 inches thick on the inside, and an air space between each wall and the plaster board:

Thickness of wall.	k	Thickness of wall.	k
½ brick	0.29	1½ bricks	0.21
1 brick	0.24	2 bricks	0.20

* This "plaster board" is a slab made of mortar and plaster of paris. It is used instead of furring and plastering, as we use.

(E) Stone walls, rubble or block masonry:

Total thickness.	Sandstone. k	Limestone. k
12 inches	0.45	0.49
16 inches	0.39	0.43
20 inches	0.35	0.38
24 inches	0.31	0.35
28 inches	0.28	0.31
32 inches	0.26	0.28
36 inches	0.24	0.26
40 inches	0.22	0.24
44 inches	0.21	0.23
48 inches	0.19	0.21

(F) Doors or wooden walls:

Thickness.	Pine. Inside. k	Pine. Outside. k	Oak. Inside. k	Oak. Outside. k
½ inch	0.52	0.56	0.64	0.70
¾ inch	0.44	0.47	0.59	0.63

	Pine.		Oak.	
	Inside.	Outside.	Inside.	Outside.
Thickness.	k	k	k	k
1 inch	0.39	0.41	0.54	0.58
1¼ inches	0.34	0.36	0.50	0.54
1½ inches	0.31	0.32	0.47	0.50
2 inches	0.26	0.27	0.41	0.43
2½ inches	0.22	0.23	0.37	0.39
3 inches	0.19	0.20	0.33	0.35

(G) Windows and skylights:

	k
Single window	1.09
Single window; double glass	[illegible]
Double window	0.46
Single skylight	1.16
Double skylight	0.48

(H) Ceilings and floors:

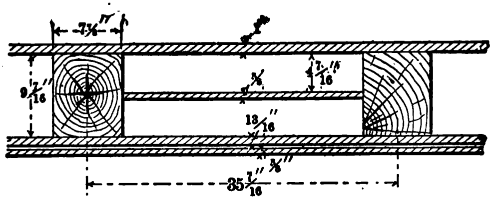

Fig. 11.—Single Flooring.

For an unheated room above a heated room, $k = 0.10$
For a heated room above an unheated room, $k = 0.07$

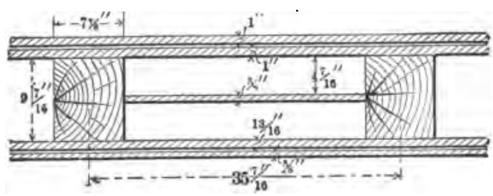

Fig. 12.—Double Flooring.

For an unheated room above a heated room, $k = 0.09$
For a heated room above an unheated room, $k = 0.06$

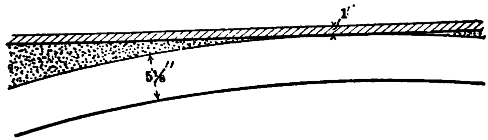

Fig. 13.—Arch with Stone Flooring.

$k = 0.21.$

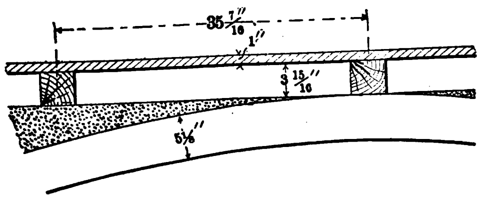

Fig. 14.—Arch with Sleepers and Single Flooring.

For an unheated room above a heated room, $k = 0.15$
For a heated room above an unheated room, $k = 0.09$

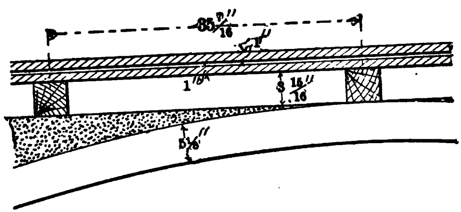

Fig. 15.—Arch with Sleepers and Double Flooring.

For an unheated room above a heated room, $k = 0.12$
For a heated room above an unheated room, $k = 0.06$

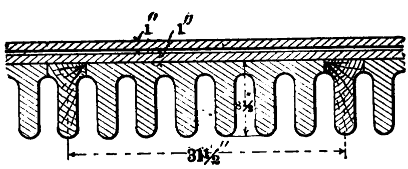

Fig. 16.—Corrugated Iron and Concrete with Double Flooring.

$k = 0.13.$

Table XIII (Calculated by the Author).

(A) Ordinary furred brick walls:

Thickness of wall.	k	Thickness of wall.	k
½ brick	0.28	2 bricks	0.18
1 brick	0.23	2½ bricks	0.16
1½ bricks	0.20		

(B) Partitions:

	k
Ordinary stud partition with lath and plaster on one side only.	0.60
Ordinary stud partition with lath and plaster on two sides	0.34

(C) Ceilings and floors:

	k
Ordinary lath and plaster ceiling separating unheated space from heated rooms	0.62
Floor, single thickness, ¾-inch, warm air above and cold space below:	
(a) No plaster beneath joists	0.45
(b) Lath and plaster beneath joists	0.26
Floor, double thickness, 1½ inches, warm room above and cold space below:	
(a) No plaster beneath joists	0.31
(b) Lath and plaster beneath joists	0.18

(D)* Outside walls of frame buildings. All of the walls are supposed to have lath and plaster inside, and an outside covering as described in the table.

Outside covering.	k
Ordinary overlapping clapboards about 7-16 inch thick	0.44
Paper and ordinary clapboards	0.31
¾-inch sheathing and clapboards	0.28
¾-inch sheathing, paper and clapboards	0.23

* These can hardly be considered much more than rough approximations, on account of the uncertainty due to leakage.

XI.—TO CALCULATE THE HEAT LOST THROUGH COOLING SURFACES.

The heat which passes through a cooling wall or other surface per hour is given by the equation

$$H=k\ (t_1-t_0)\ S,$$

where k is the constant discussed in the previous articles, whose value for most surfaces may be obtained from one of the tables given in Paragraph X;

t_1 is the temperature of the warm air in contact with the wall or cooling surface ; t_0 is the temperature of the cool air ; and S is the area of the cooling surface in square feet.

H must be calculated for each wall and each cooling surface, floor or ceiling, of a room, and the sum of these quantities is the total heat lost per hour for that room. The different values of t_0 to be used are given in Table II. For the walls, windows and other vertical surfaces of a room whose hight from floor to ceiling is not over 10 or 12 feet the value of t_1 used may be taken from Table I. But where the hight of the room is greater than 10 or 12 feet the temperature of the warm air is greater near the ceiling than near the floor, and the mean temperature of the air must be taken as t_1. Rietschel calculates the temperature, t^1, of the air at the ceiling of a room by the formula

$$t^1 = t + 0.03\,(h-10)\,t,$$

where t is the temperature at a distance of $4\frac{1}{2}$ or 5 feet, "head high," from the floor.

The temperature at the floor is assumed to be t, and the mean temperature, t_1, is given by the equation

$$t_1 = \frac{t^1+t}{2} = t + 0.015\,(h-10)\,t.$$

Rietschel says, however, that t^1 should not be assumed as greater than about 1.3 t, and therefore it follows that t_1 should not be assumed as greater than 1.15 t.

When determining the loss of heat from a warm room through a ceiling, Rietschel takes t_1 as equal to t^1, which he calculates by the equation given above; and when determinating the loss of heat from a warm room

through a floor Rietschel takes t_1 as equal to t, the temperature "head high" above the floor.

Neither Klinger nor Recknagel follows the method adopted by Rietschel of determining the mean temperature of the air in contact with the cooling wall and using it in calculating the heat loss; but they use the temperature that is to be maintained in the room, measured about 5 feet above the floor, when calculating the heat losses, and increase these losses by an amount which depends upon the hight of the room, as shown in Paragraph XII.

XII.—ADDITIONS TO THE CALCULATED HEAT LOSSES.

The German engineers usually make certain additions to the heat losses determined by the method shown in the previous pages, which depend upon unusual exposure or upon interruption in the heating.

The increases recommended by Recknagel are: 25 per cent. for surfaces having a northern, northeastern or northwestern exposure; 20 to 30 per cent. for surfaces exposed to winds; 10 per cent. of the total heat losses for rooms more than 13 feet from floor to ceiling; 20 per cent. of the total heat losses for rooms in which the heating is interrupted daily.

The increases recommended by Klinger are, in general: 20 per cent. for corner rooms and 10 per cent. for other rooms. For more exact work: 10 per cent. for surfaces having a northern, eastern, western, northeastern or northwestern exposure; 5 per cent. for corner rooms; 3 per cent. for rooms from 12 to 14½ feet from floor to ceiling; 6½ per cent. for rooms from 14½ to 18 feet from floor to ceiling; 10 per cent. for rooms more than 18 feet from floor to ceiling; 10 per cent. when the heating is continued during the day only and the building is closed up during the night;

30 per cent. when the heating is continued during the day only and the building is open during the night; 50 per cent. when the building remains for long periods without heat.

Rietschel recommends the following increases on account of exposure: 10 per cent. for surfaces having a northern, eastern, northeastern or northwestern exposure; and 10 per cent. additional for surfaces that are especially exposed to the wind.

In regard to the increase in the heat loss of a room on account of interrupted heating, Rietschel says, very truly, that this depends upon the length of time from the end of one heating to the beginning of the next, upon the thickness of the walls, and upon the time spent in heating the room or building. And he gives four empirical equations, for different cases, for determining the amount of heat that must be added to that transmitted through walls and other cooling surfaces in order to determine the heat which the heating plant must supply. Two of these equations are for rooms, such as churches and assembly halls, that are expected to contain a large number of people and to be used for but a short period at any one time, while the others are for rooms of buildings, such as dwellings, schools and office buildings, that do not remain for any long period without heating. The formulas for the first class of rooms are rather complicated and need not be given here, but those for the second class of rooms are given.

The heat, A, to be added to the heat lost by the walls and cooling surfaces per hour is, for rooms which are heated daily, but with interruption during the night,

$$A = \frac{0.0625\,(n-1)\,W_1}{z};$$

and for rooms which are not heated daily,

$$A = \frac{0.1\,(8+z)\,W}{z}.$$

W_1 is the heat lost per hour through the outside walls and windows and other cooling surfaces which have to be practically rewarmed, and it includes the increases made on account of exposure, wind, hight, &c.; W is the total heat lost per hour; n is the number of hours from the ending of the daily heating in the evening to the beginning in the morning; z is the number of hours from the beginning of the heating in the morning to the time when the building is thoroughly heated. A should not be taken greater than one-third W.

Rietschel says, also, that z may be taken as about 3 for schools and dwellings, and 5 for meeting halls; and that n may be taken as about 7, from 10 p.m. to 5 a.m., for dwellings, and about 12, from 5 p.m. to 5 a.m., for schools and office buildings.

It may be noticed, as what is a great difference between the practice of the German engineers and that of the engineers in this country, that the German engineers never seem to make any allowance for the leakage of cold air into a heated room. They, apparently, do not have the great leakage to contend with that we do in this country. This is probably due to the fact that their houses are all well built, and every precaution is taken to avoid leakage of air into the rooms; and that the windows of the houses are usually double, and are always hinged like double doors, and are not make to slide up and down in their frames, as are the windows of houses in this country.

XIII.—DETERMINING THE HEAT LOST.

In order to make what has been said more clear, the heat lost per hour by the room shown in Fig. 17 will be determined.

It will be supposed that the outside walls are two-

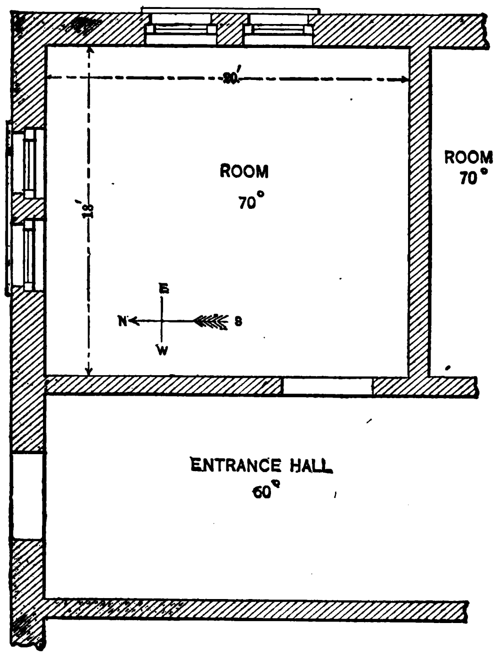

Fig. 17.

brick walls, furred on the north side but not on the east side; that the wall between the entrance hall and the room is a one and one-half brick wall, plastered on both sides; that there are two windows in the north wall and two in the east wall, each 4 x 10 feet; that the hight of the rooms is 14 feet; that the door is 3 x 9

feet; and that the room is over an unheated cellar and has a floor 1½ inches thick, but no plaster on the underside of the joists. It will also be assumed that when it is zero outside the temperature of the cellar is 32 degrees, as given in Table II; that of the room is 70 degrees; and that of the hall is 60 degrees.

The heat lost through each cooling surface will be calculated by the equation $H = k (t_1 - t_0) S$.

The values of k are as follows:

North wall, two-brick, furred, Table XIII (A)	0.18
East wall, two-brick, Table XII (A)	0.24
Partition wall, one and one-half-brick, both sides plastered, Table XII (A)	0.26
Windows, single, Table XII (G)	1.09
Floor, 1½ inches thick, Table XIII (C)	0.31
Door, assume 1¼ inches thick, Table XII (F)	0.34

The average temperature of the air in contact with the floor and the door may be assumed as 70 degrees; and that of the air in contact with the walls and windows may be obtained by Rietschel's formula, given in Paragraph XI, $t_1 = t + 0.015 (h - 10) t$, in which t is 70 degrees and h is 14, so that for the walls and windows, $t_1 = 70 + 0.015 (14 - 10) 70 = 74$; t_0 is 0 degree for the outside walls and windows, 32 degrees for the floor, and 60 degrees for the partition wall and door.

In determining S for the outside walls we must subtract from the total gross area of each wall the areas of the windows in it, and in determining S for the partition wall we must subtract from the gross area the area of the door.

The values of S are as follows:

	Square feet.
Windows in north wall, 2 x 4 x 10	= 80
Windows in east wall, 2 x 4 x 10	= 80
North wall, 14 x 18 — 80 = 252 — 80	= 172
East wall, 14 x 20 — 80 = 280 — 80	= 200

	Square feet.
Floor, 18 x 20	= 360
Door, 3 x 9	= 27
Partition wall, 14 x 20 — 27 = 280 — 27	= 253

The product of k, $t_1 - t_0$, and S for each cooling surface, plus the increase on account of exposure, is the heat lost per hour through that surface, and the sum of the quantities of heat lost through the different surfaces is the total heat lost per hour by the room.

The quantities of heat lost per hour through the different surfaces are:

North wall, 0.18 (74 — 0) 172	= 2,290
10 per cent. for northern exposure	= 230
North windows, 1.09 (74 — 0) 80	= 6,450
10 per cent. for northern exposure	= 650
East wall, 0.24 (74 — 0) 200	= 3,550
East window, 1.09 (74 — 0) 80	= 6,450
Floor, 0.31 (70 — 32) 360	= 4,240
Door, 0.34 (70 — 60) 27	= 90
Partition wall, 0.26 (70 — 60) 253	= 660
Total heat lost per hour	= 24,610

If it is supposed that the room is heated only during the day we may determine the additional amount of heat to be added to the above by means of Rietschel's formula, given in Paragraph XII:

$$A=\frac{0.0625\,(n-1)\,W_1}{z}.$$

W_1 is, in this case, the total heat lost through the outside walls, the windows and the floor, and is equal to 23,860 heat units. If we suppose that the heat is turned on in the morning at 5 a.m., and is turned off at 6 p.m., n is 11, the number of hours from 6 p.m. to 5 a.m.; and if we suppose that the building is thoroughly warmed by 8 a.m., z is 3, the number of hours from 5 a.m. to 8 a.m. Hence we have

$$A=\frac{0.0625\,(11-1)\,23,860}{3}=4970.$$

Therefore the total amount of heat which the heating apparatus in the room must be able to furnish per hour is 24,610 + 4970 = 29,580, or about 30,000 heat units.

XIV.—TO DETERMINE THE HEATING SURFACE REQUIRED.

German engineers recognize several different systems of heating, some of which are like those in common use in this country and one or two of which are different, but in determining the amount of heating surface required for any system to supply the heat lost by a room per hour they follow the same general method. They determine by calculation or otherwise the amount of heat that will be emitted per hour by each square foot of the heating surface, and divide the heat required by this amount. Hence, if H is the heat required per hour for a room or a building, h the heat emitted per square foot of the heating surface per hour, and S the number of square feet of heating surface required, we have

$$S=\frac{H}{h}.$$

The systems with which we have to do here are water heating and steam heating, and, therefore, they only will be discussed.

The German engineers divide the water heating systems into two classes, warm water systems and hot water systems; and each of these is further divided into two subdivisions.

The warm water systems are subdivided into low pressure and medium pressure warm water heating systems. The low pressure warm water heating system corresponds to our ordinary open hot water heating system. The temperature of the water is

never supposed to be greater than 212 degrees, and the system is open to the atmosphere at its highest point. In the medium pressure warm water system the temperature of the water may be as high as 266 degrees, and the system is not open to the atmosphere at any point. This system resembles our closed hot water system.

The hot water system is often called "Perkins' system." It is subdivided into medium pressure and high pressure hot water systems, according to whether the temperature of the water is between 266 and 284 degrees, or between 284 and 356 degrees.

The main difference between the warm water system and the hot water system is that the first consists of a boiler or heater, several radiators, and pipes of different diameters connecting the heater to the radiators; while the second consists simply of an endless pipe of, usually, a uniform diameter, part of which serves as a heater and parts serve, also, as radiators. That part of the pipe which serves as a heater is usually bent to form a coil and is placed directly in contact with the fire of a furnace.

Steam heating systems are divided into high pressure and low pressure steam heating systems, according to the pressure of the steam in the boiler. The high pressure systems may carry any pressure as high even as 75 or 90 pounds by the gauge, while the low pressure systems may not carry more than 7.5 pounds, one half an atmosphere, by the gauge. The high pressure systems are subject to official inspection and supervision, while the low pressure systems are not. This is very similar to the distinction often made in cities in this country, where boilers carrying a higher pressure than 15 pounds by the gauge are subject to

the inspection and supervision of the city officials, and the users of such boilers must employ licensed engineers.

The German engineers make about the same distinction between direct radiation and indirect radiation that we do, although they include all heating done by indirect radiation under "air heating," just as they do furnace heating.

XV.—VALUES OF h.

As usual, the German engineers have a method of calculating the amount of heat which will pass through 1 square foot of heating surface per hour. They say that $h = c\ t$, where c is a constant depending upon the kind of surface, the hot fluid, and the cold fluid; and t is the difference between the average temperatures of the hot and cold fluids.

According to Rietschel c has the following values for heat transmitted:

	c.
From air or smoke through a clay plate about ⅝ inch thick to air	1.00
From air or smoke through a cast iron or sheet iron plate to air	1.4 to 2.0
From air or smoke through a cast iron or wrought iron plate to water, or the opposite	2.6 to 4.0
From steam through a cast iron or wrought iron plate to air	2.2 to 3.6
From steam through a metal wall to water	160 to 200

In practice, however, the German engineers usually take the value of c smaller than given above. This, of course, means using a factor of safety, as there are always many things which tend to make the value of h smaller than it might be.

The values of h which, according to Rietschel, are usually adopted for steam and warm water radiating surfaces are given in Tables XIV and XV.

Table XIV.—Rietschel's Values of h for Steam Radiators.

(A) DIRECT RADIATION.

Heating surface.	Values of *h*. Low pressure, less than 7.5 lbs. by gauge.	High pressure, higher than 7.5 lbs. by gauge.
Smooth pipes, vertical	260 to 275	315 to 330
Smooth pipes, horizontal	275 to 295	330 to 350
Pipe coiled	240 to 260	295 to 315
Cast iron ribbed radiators	150 to 185	185 to 220

(B) INDIRECT RADIATION.

Heating surface.	Values of *h*. Low pressure, less than 7.5 lbs. by gauge.	High pressure, higher than 7.5 lbs. by gauge.
Pipe coiled, not higher than 3 feet 3 inches	405	450
Pipe coiled, higher than 3 feet 3 inches	370	430
Cast iron ribbed heater, not higher than 3 feet 3 inches	295	325
Cast iron ribbed heater, higher than 3 feet 3 inches	280	315

Table XV.—Rietschel's Values of h for Warm Water Radiators.

(A) DIRECT RADIATION.

Heating surface.	Values of *h*. Temperature of water not higher than 212 degrees.	Temperature of water higher than 212 degrees.
Vertical pipe radiator:		
One row	150 to 165	185 to 205
Two rows	140 to 155	175 to 195
More than two rows	130 to 145	165 to 185
Smooth pipe up to 13 feet in length, vertical	165 to 185	205 to 220
Smooth pipe up to 13 feet in length, horizontal	185 to 205	220 to 240
Pipe coiled	150 to 165	185 to 205
Cast iron ribbed radiators	85 to 110	110 to 140

(B) INDIRECT RADIATION.

Heating surface.	Values of *h*. Temperature of water not higher than 212 degrees.	Temperature of water higher than 212 degrees.
Pipe coiled, not higher than 3 feet 3 inches	245	305
Pipe coiled, higher than 3 feet 3 inches	235	295
Cast iron ribbed heater, not higher than 3 feet 3 inches	185	235
Cast iron ribbed heater, higher than 3 feet 3 inches	175	

The cast iron ribbed radiators mentioned in the tables are apparently very inefficient; they consist, as shown in Fig. 18, of a rectangular box with two flat sides furnished with ribs inclined at an angle of about 45 degrees. These ribs are about ¾ or 1 inch apart, and project about 2 or 2½ inches from the surface of the radiator.

The vertical pipe radiators are made of short lengths of wrought iron pipe. They are very much like some radiators used in this country.

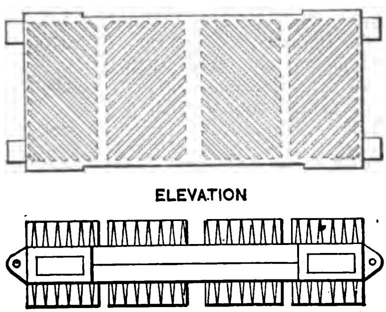

Fig. 18.—Ribbed Radiator.

The values of h given by Rietschel are somewhat different from those given by Klinger, but it is unnecessary to give Klinger's values.

It is interesting to compare the values of h given in the tables with the values we usually employ in this country. We usually assume a value of h between 150 and 200 for open hot water heating systems, and between 250 and 300 for low pressure steam systems, where the pressure is not to exceed 5 pounds by the gauge.

Example XII.—How many square feet of warm water direct radiating surface are required for a room which loses 15,000 units of heat per hour through its walls and cooling surfaces?

If we assume that the temperature of the water is not to exceed 212 degrees, and that we will use vertical pipe radiators with two rows of pipes, we find from Table XV (A) that h varies from 140 to 155, and we may take it as 150. Hence we have

$$S=\frac{H}{h}=\frac{15,000}{150}=100.$$

XVI.—ESTIMATING THE HEATING SURFACE REQUIRED.

Klinger gives the following values for the number of cubic feet of space that may be heated by 1 square foot of heating surface. These values are to be used, of course, only in estimating roughly the approximate number of square feet of heating that will be required to heat a given building or room.

	Cubic feet of room heated by 1 square foot of radiator surface.
Water heating, direct radiation.	
Temperature of water not greater than 203 degrees..	33 to 49
Temperature of water not greater than 248 degrees..	about 59
Steam heating, direct radiation.	
High pressure steam..............................	98 to 130
Exhaust steam from engine.........................	82 to 98
Low pressure steam, cast iron radiators.............	49 to 66
Low pressure steam, wrought iron radiators.........	98 to 130

It is probable that the cast iron radiators meant above are similar to those mentioned in the previous article, which are very inefficient, and that the wrought iron radiators are vertical pipe radiators.

Eric
psd C